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A Study of

Panama Canal Plans and Arguments

ADDRESSED TO
THE HON. GEORGE C. PERKINS
United States Senator
California

WM. HAM. HALL
M. Am. Soc. C. E.

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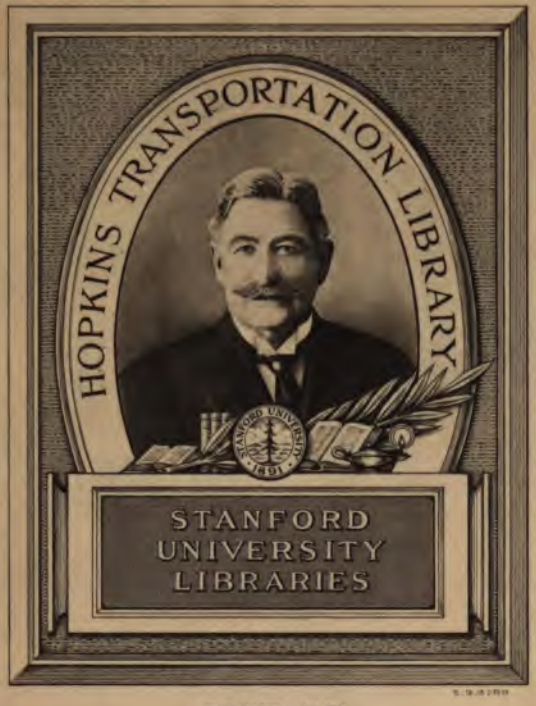

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ADDRESSED TO

THE HON. GEORGE C. PERKINS

United States Senator

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WM. HAM. HALL

M. Am. Soc. C. E.

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INTRODUCTORY LETTER

SAN FRANCISCO, August 7, 1905.

HON. GEORGE C. PERKINS, *U. S. S.,*
San Francisco, Cal.—

MY DEAR SENATOR:—

This is the third and last part of my communication to you relative to Panama Canal matters. In Part I, I traced the development of Panama Canal engineering conflicts. In Part II, I reviewed and commented upon several Panama Canal construction projects. In the present letter I summarize the important counts made in the two former parts of my work, together with several additional points, and develop more fully their bearing on the practical problem of selecting a plan. It is not my purpose to advocate any particular plan, but to formulate a study of the question of determining upon one, and to show where, in the light of the data available to the public, such an analysis as that which I have been able to make, seems to lead.

Very respectfully yours,
WM. HAM. HALL,
M. Am. Soc. C. E.

OUTLINE: PART III.

PANAMA CANAL PLANS AND ARGUMENTS—A STUDY

The Necessary Practical View-Point.

The Business End of the Problem.
The Danger in Technical Exclusiveness.
The Practical and Safe Course.

A Review: From the Sea-Level, Upwards.

The Weakness of the Mean-sea Plan.
The Strength in the Sea-level Idea.
The Higher and the Stronger View-point.
The Problem.
Uncertainties as to Cost.
The Below-sea-level Work—Rock.
The Below-sea-level Work—Gravels and Sands.
The Below-sea-level Work—Retaining Walls.
Uncertainties as to Safety.
Uncertainties with Sea-level Terminal Divisions.
The Flood Disposal Complications.
The Mountain Tunnel Spillway Idea.
The Least Objectionable Alternatives.
One-lock-lift or Two-lock-lift.

A Review: From 90-foot Level Downwards.

The Difference Between Lock-canal Proposals.
The Merit of Simplicity in a Plan.
The Claimed Advantages of Only One Lake.
The Availability of the Gigante Spillway.
The Advantage in the Alhajuela Reservoir.
Unsoundness of the 90-foot-summit Plan.
Bearing of the Gigante Spillway Feature.
Advantages of Alhajuela Reservoir.
Some Closing Comparisons.

SOME GENERAL CONCLUSIONS

The Most Feasible and Practicable Plan.
Possibilities of Enlarging Canals.
Advantages of the Larger Canals.
Advantages of Lake Waterway.

A Final Summarization.

PART III.

A SUMMARY OF PANAMA CANAL PLANS AND ARGUMENTS

The Business End of the Problem.

In the first place, it presses upon me that this question of a plan, is not alone an engineering one, as some of my professional brothers seem to have persistently regarded it. The Act of March 3rd, 1899, instructed the Isthmian Canal Commission provided for therein, to consider the various canal routes which had been talked of, and to report its opinon as to "the most practical and feasible route" for an Isthmian Canal, "to be under the control, management and ownership of the United States." The Commission reported in favor of the Nicaragua route, but, as it later turned out, not from the engineering view point; for immediately other objections were practically removed, it wheeled about and recommended the Panama route. (Part I, p. 15). This was not engineering. It was business policy, and, I expect, a wise exercise of it. The Technical Committee of the new Panama Canal Company (Part I, pp. 12 and 13), though, as an engineering construction, it preferred a canal with a 66-foot summit level, recommended its company to build one with a 97.5 foot summit level. This also was business policy, and, under the circumstances, probably was sound. But where in all else pertaining to the work of Engineering Boards and

Commissions connected with this matter, have we been told, much less shown; that business prudence has been considered?

The Danger in Technical Exclusivism.

There has been talk as to "the type to be given the Canal," and we have heard much about the relative merits of various "types" of canals, one might almost suppose that canals were to be had in sections, of the several "types," compressed but expandable, which might be transported to the Isthmus, and there fitted to the country. I fear, my dear Senator, that this kind of talk, has served more to distract attention from a proper study of the actual problem in hand, than it did to effect a wise solution of it.

We have also heard of the boldness with which the problem should be attacked by the engineer, because it is a case of "a great Government developing its possessions." But this thought, it would seem, has contributed more to engineering rashness than real boldness. The boldest thing often which an engineer can do is to take business acumen and political wisdom into his counsel, in the face of the purely technical leaning of the academic majority of his brothers. This United States is one of the large "pebbles" on the beach of Nations, to be sure, but such pebbles are rolled by waves of popular sentiment. And the engineer who plans for the Panama Canal a construction which, though the best engineering work if it could be accomplished, is widely open to political attack, either as being bold and risky from the construction view point, or extreme or uncertain as to cost in money or time, may

be doing that which will bring the entire enterprise to disaster or to a very long postponement of realization.

The Practical and Safe Course.

It would seem at this point of time that there has been as much necessity for specially instructing the Commissions to select "the most practical and feasible" *plan* for an Isthmian canal *to be constructed* by the United States, as there was for directing in the above quoted words, their action with respect to selection of a *route*. This thought of business (and political) practicability should be held constantly in mind by him who really desires to see the American people stand, to the end, by an expenditure of $150,000,000 to $200,000,000 of their money in accomplishing this great work in a foreign land. The problem, therefore, involved in the selection of a plan for the Panama Canal, even for construction by "a great Nation developing its possessions" is not wholly an engineering one.

A REVIEW: FROM THE SEA-LEVEL, UPWARDS

The Weakness of the Mean-Sea Plan.

Recalling to mind the former parts of my communication, I suppose you will have seen these indications.

First—That, for the Isthmus of Panama, a mean sea-level canal would be, in a sense, down "in a hole," and that no reasons have yet been given which are convincing to the conclusion that the additional money necessary to put it there should be expended by the American people, at this time. (Part II, pp. 43-47).

Second—That a Panama Canal cannot, within practicable cost in money and time, be built, maintained and operated without the handicap, on size of ships using it, due to a lock (the necessary tidal lock on the Pacific side), and that half a dozen locks, all being made the same size, would be no more a handicap to commerce, through restricting ship dimensions, than one would be. (Part I, pp. 8, 9 and Part II, p. 47).

Third—That a canal, with a lock at each end, instead of at one end only, and having a water surface at Panama high tide level, in place of at mean sea level, can probably be built for materially less money, than the mean sea level canal, and the fact of its having two locks in lieu of one would not render it materially more of a handicap on commerce. (Part II, pp. 47-49).

Fourth—That a canal having two locks, but with their lifts fixed at 30 to 40 feet, can be built for less money and in less time than one with the two locks and the lift to high tide level, only, and that the additional time taken by lockage to the 30 to 40-foot plane would be insignificant. (Part II, p. 50).

In these four propositions, my dear Senator, you see what must, at this distance and with the data at our disposal, appear to us to be points of weakness of the mean-sea level general idea for the Panama Canal. Albeit, the proposed application of it has other weaknesses, as we will presently see, and which, *under the circumstances,* we must consider.

The Strength in the Sea-Level Idea.

Nevertheless, there is strength in the general plan also,

more particularly when we look at it from several high and distant view points. That of maintenance for all time, that of possible ultimate absolute freedom of passage, and that of military preservation and protection. Notwithstanding what I have before written and more which will hereinafter appear, if a canal could be cut for a water plane at sea level from ocean to ocean, of sufficient size to admit of rapid passage of the largest ships, and with flanking slopes very flat and well removed from it, unquestionably, it would be the best obtainable water passage between the continents.

With all these attributes it would be the most easily maintained, the most readily used, the safest from harm by an enemy, and the most easily repaired if damaged; and, if it were big enough, there is actually a possibility, though a remote one, that it might be used without lock-hindrance at all. The Straits of Magellan join the same two oceans. There is a much higher tide at one end of these straits than at the other. They are open, lock-free and navigable. But the Supreme Architect made this waterway. His forces have enlarged it, until there is room for the rushing tides, and though sailing vessels dare not venture through because of these, steamships with their power may stem them or speed away from them, and yet keep off the rocks which are lashed by them on either side.

The Higher and the Broader View Point.

But, my dear Senator, whenever we climb to these heights, to be fair, we must use them from whence, to view the *whole* subject broadly. Above all, we must look at the possibilities to us; and justice to ourselves as well as

to our principals and our subject, demands that we grasp those which seem to be most surely within our present command.

Therefore, in all which I have written and do write, on the relative merits of the sea-level or the lock-level controversy, it must be understood that I mean *their merits for the Panama route, as these must be viewed in our American, intensely practical way. "We will build this work now, and make it a success for this time. We would like to do it so that it may be the thing for all time. But we will not fail now in the building, because of doubt or difference of opinion as to what the canal should be in the distant future."* I think this would be the view of Americans in general if appealed to. At all events, it is the view I take, and from its point of vantage I write.

The Problem.

And just here we must remember that it is not alone the passage of vessels which must be provided for. The ships guided by man from ocean to ocean will make one use of the canal. The waters impelled by nature and falling on the shed tributary to it will make another use of the water-way. Either man must provide other accommodations for those waters, or he must make his ship waterway suitable to receive and pass them and provide adequate and safe means for their entrance to it. With these preliminary thoughts set out in order that you may not misunderstand my purpose, I return to the question of a plan itself.

Uncertainties as to Cost.

Aside from the fact that argument has not been adduced

to uphold the claims of practical superiority for a mean-sea level Panama Canal, and apart from the further fact that it would seem to require, on the estimates already made, about $36,000,000 more than a 30-foot level one, without having any material advantage over the latter, it would have, both in construction and in maintenance, great comparative disadvantages, and these I have as yet scarcely hinted at. Let us look for a moment at some of them.

A mean-sea level canal of the dimensions of waterway contemplated under the American plannings would involve the excavation of more than 60,000,000 cubic yards of material below the plane intended for its water surface, of which 12,000,000 or more, cubic yards are probably "rock," or hard, indurated clay, which will have to be blasted. All of this will probably have to be worked out from under water, except it may be that the great cut from Obispo to Pedro Miguel or Miraflores, can, to some extent, be kept unwatered, while the work is in progress. But to what extent this can be counted upon in a climate of torrential rains and a material of volcanic formation, with the Chagres River and other streams "overhead," so to speak, is and must until tried remain uncertain.

The Below-Sea-Level Work—Rock.

All of the material in the below-sea-level prism of the great backbone cut, as well as much of that within the same prism elsewhere along the work, is expected to be "rock." Excavation of such material from under water, the Isthmian Canal Commission estimated at $4.75 per cubic yard, while for the removal of soft rock above water

the figure was 80 cents, and for hard rock, $1.15. Contemplate a moment the difference; $4.75 is more than four times the $1.15 or about six times 80 cents. An uncertainty therefore will be as to the amount of material to be excavated below water plane which will cost from four to six times the normal rates above it. With the possibilities ranging from somewhere between ten to twenty million cubic yards, it must be admitted that there is a lot of room for money cost exceeding the estimates on this item. Not leaving this one point of uncertainty as to amount of underwater rock excavation which will have to be handled, the unanticipated money cost which this part of the work might entail, might be as nothing to the delay in time consequent upon it. The blasting and removal of rock under water is one of the most stubbornly slow processes which the engineer is called upon to conduct.

But this point is only the commencement of the special uncertainties attendant upon construction of a sea-level Panama Canal. The dredgeable material from below water was estimated at twenty cents a cubic yard. That estimated as dredgeable which turns out to be not so—that which will have to be blasted and then scooped or bucketted out—will be "rock," and will cost about the $4.75 per cubic yard, or about twenty-four times the 20 cents. Now it is expected that rock will be encountered under dredgeable material in a number of places, and some allowance has been made therefor in the estimates. But this item of cost of the under-water part of the work, will largely remain, both as to measure of quantity and as to resistant quality, undetermined until the canal shall have been built.

But it is not alone as to how much material will have to be removed at approximately $4.75, and how much at 20 cents, that we would have to eat this pudding before we could prove whether it were good or bad. There is nothing which so knocks out machinery dredging in soft material and demoralizes the whole work as an under stratum of hard rock encountered here and there. Another chance to drop a large "wad" as well as several years not counted upon.

The Below-Sea-Level Work—Gravels and Sands.

But, again, there is yet more uncertainty in this connection. Who knows how those soft gravels and sands, and, possibly, quick sands, lying in the middle Chagres River gorge, are going to behave when dredged through to a plane 35 feet below sea level. They have been described by the Isthmian Canal Commission of 1899-91, as veritable terrors on which to found a Bohio dam. The Engineering Committee of the first Panama Canal Construction Commission, in February of this year, gave them an equally bad reputation as dam sub-strata, in the realization of any lock canal project. But they complacently expect them to "stand pat" under water, around a dug out canal cross section, having side slopes of one on two or three. The chances are that there will be disappointment in this—that large volumes of such materials, over and above those in the originally excavated sections, will come into the water-way and have to be removed by dredging. The character ascribed to them by the reports I have reviewed in former parts of my communication, seems to justify such anticipation. More cost and more

time. Greater expense and special inconvenience in maintenance.

The Below-Sea-Level Work—Retaining Walls.

The Isthmian Canal Commission of 1899-1901 considered that so much of their planned water way as was flanked by the excavated mountain slopes, about six miles, should be walled up on each side, for the treble purpose of holding the slope, receiving the wave wash, and retaining a level berm for railway purposes on each side of the water. Doubtless this was sound. Such retaining walls would be decidedly more necessary in the case of a sea level canal. Supposedly, they have been provided for in the plannings and estimates of the late Chief Engineer, but the Engineering Committee which reported upon those plans, did not go into these details, so we do not know definitely. The reasons which called for retaining walls flanking six miles of the waterway in the summit cut for a 90-foot water plane canal, would make them necessary, apparently, for some miles greater length of the cutting for a sea-level canal. If, in addition to the above, the before anticipated slip, creep or wash of the gravel and sand sides of the cutting through the middle Chagres division of the work is to be prevented by retaining walls, the total length of such construction necessary would appear to be about fourteen miles—from Bohio to Miraflores. Whatever this length may be, however, the present point is that the construction will be almost wholly below the plane fixed for the water surface of the canal; and to a depth of about five feet, or more, greater than the navigation depth itself.

How is this work to be put in? Miles on miles of concrete wall at the foot of slopes more or less unstable, and with foundations 40 feet or more below sea level, must be built. I am not doubting ability to do it. It is entirely feasible. I am calling attention to the construction as another item of uncertain cost in money and in time.

Consider the possible cost and uncertainty of keeping that fourteen miles of below-sea-level cutting unwatered, if the attempt be made to do this, so as to cheapen excavation and wall building. Consider the possible additional uncertainty and cost of keeping the wall foundation pits unwatered at the foot of such slopes, through such materials, in such a climate.

Or, if this excavation and wall building is to be handled under water, consider the enormous volume of rock to be "shot" below water, scooped therefrom and carried away, and consider the length of coffer dam or of caisson work which would have to be organized, and operated without mishaps if it is to be safely estimated beforehand. An experienced contracting firm would leave a very large margin, for safety, in estimating a "tender" price for that work. Will an engineer estimating for the Government be justified in doing otherwise? Can his estimate results in any event be depended upon for the purposes of this Government?

Uncertainties as to Safety.

I would like, my dear Senator, to stop this line of thought right here, but I cannot. And, therefore, I say, if you do not picture to yourself on the above showing enough of uncertainty in outcome to "give us pause" and

prompt us to "accept the ills we have" above sea level in this Panama Canal matter, rather than "fly to others we know not of" below that plane, consider the significance of the available description of the Culebra Cut materials. Mr. George P. Morrison's words are: "While in the upper part of the cut, where the work was "first opened, there is some soft and slippery clay, nearly "the whole of this excavation must be made through a "material which has generally been rated as rock. It is, "in fact, an indurated clay, not firm enough to be classed "as shale, but perhaps quite as hard to work. It is in-"tersected here and there by thin strata and dykes of "hard limestone. It is a material which would weather "rapidly and go to pieces in a Northern climate where there "is frost; in the damp warm climate of the Isthmus it "does better, but when fragments are immersed in water, "they fall into powder, and it would evidently be unsafe "to expose the unprotected sides of this excavation to the "wash of the water in the canal." (Trans. Am. Soc. C. E., Vol. L, p. 170.)

This description was given by Mr. Morrison in explaining the necessity for the retaining walls above adverted to. But, if "it would evidently be unsafe to expose the un-"protected sides of this excavation to the wash of the "water in the canal," how much safer can we assume it to be to leave them exposed on the projected side slopes of one to one, all the way above canal bank to mountain top—one hundred, two hundred, three hundred feet above us—and under influence of 80 to 100 inches of rainfall per year, coming in tremendous downpours within short spaces of time?

My dear Senator, I am no pessimist on the Panama Canal project. I am a friend to it. But I have had a tropical country engineering experience, which happens to be just in point on this subject—the stability of cut slopes in a volcanic formation, now appearing as undurated, seamed clay, under excessive rainfalls; and I tell you that the true friend of the Panama Canal will not knowingly plan for more of such exposed slopes than are absolutely necessary. The deeper the cut is made, the more slope is exposed. The danger from it increases in greater ratio than its height increases.

If, by that great cutting through such a formation, inclined seams or dykes on which immense slides will occur under such excessive rainfall influence, are not developed, we may consider the outcome as a colossal good fortune. There is a possibility of such mountain-side movement under those conditions as would come near to defeating the whole work within limits of bearable cost.

I do not say such a thing is probable, but it is possible. Every foot deeper you go with that cutting adds to the danger of slashing across the base of inclined seams or dykes and leaves above you greater weight of material and greater area to receive rainfall to start the slip.

It is reasonable to assume that the 40 feet of additional cutting necessary to put a canal water plane at mean tide level, would more greatly endanger the construction from the causes described, than the 80 feet of cutting next above it.

There has been a lot of talk on the point above, made against the whole Panama Canal project. I make it solely

in the interest of business prudence in selecting a plan to carry out that project. From all the foregoing argument it would seem that the bottom of the canal in its summit level should be kept above ocean water plane.

Uncertainties Within Sea-Level Terminal Divisions.

But, returning to below-sea-level causes for uncertainty, we have thus far thought of them only as present through that part of the work recommended to be above sea level by the Isthmian Canal Commission of 1899-1901, from Bohio to Miraflores.

What I have said, therefore, is applicable only to the final project of the Engineering Committee. But from La Boca to Miraflores and from Boca Mindi to Bohio the 90-foot summit level project is also planned to be at sea level. Allowing for the 10-foot low tide drop in the Pacific the canal waterway would have to be excavated to 45 feet below mean sea to get a minimum 35-foot navigable depth, at the Pacific end. The 8.6 miles from Miraflores to the 6 fathom line in Panama Bay, all through very low ground, involves in the neighborhood of 7,000,000 cubic yards of excavation, practically all below water, of which about 1,400,000 cubic yards are rock, underlying the soft mud and sand. 5.50 miles of this division are through the swamps within the mouth (Boca), where, as I have before pointed out (Part I, pp. 34-39, and Part II, p. 78), a dam possibly may be constructed to make a navigable terminal lake over the swamp, in lieu of cutting a canal down into and through it.

The advisability of this seems to be further indicated by the fact that it has been authoritatively proposed to

construct the canal at less than full depth through this division, to save the cost of blasting and dredging rock from under water, until such time as commerce might demand the full depth at all stages of tide. If this course were adopted, large vessels would have to await high tide in order to get over the shallow. A lock detains a vessel half an hour. To avoid detentions of six hours, more or less, for the largest vessels (battleships, for instance) at this Panama swamp division, on the sea level plan, some millions of dollars extra will have to be spent in rock excavation at depths as great as 35 feet at low, 45 feet at mean, or 55 feet at high tide. I am not condemning this proposal, I am pointing out that it ought to be proven to be the best and most advisable before it is made part of a plan. A similar word of caution might be applied to the tide level proposition at the Atlantic end. No one knows just how much rock will be encountered under the mud and sands there.

Does it not, on these grounds, look as though prudence prompts the raising of the canal by a one-lock lift, not only through the great cutting and Middle Chagres Valley, but for as much of its length as possible, namely, from Boca Mindi to La Boca—from the edge of the Atlantic to the margin of the Pacific? (Part I, pp. 35-39. Part II, pp. 75-79.)

The Flood Disposal Complications.

But when we canvas the point further this apparent advisability calls to itself still other support. The Chagres River comes to the canal line at Obispo with a bottom elevation of about 40 feet, and a flood plane level of 60 to

65 feet. If the canal water plane, be placed at mean sea level, all water permitted to come to it from the upper Chagres would have to be dropped the 40 to 65 feet. The Engineering Committee seems to consider that it should provide for currently passing, at time of flood flow, at least 15,000 cubic feet of water per second out of its projected Gamboa reservoir. The dropping of 15,000 second-feet of water 60 feet in elevation would be equivalent to hitting the cushion provided to receive it with the force of over 90,000 horse-power. A large basin would have to here be built to receive this water. At best, the construction of such a basin would be fraught with difficulty and uncertainty as to cost. Think of what might be the effect of floods coming into it, inopportunely, during course of building. Think of the duty it would have to perform after it was done. The volume of water at Niagara is far greater; the fall is three times as much, but a look at the Horseshoe Falls into Niagara's gulf, making due allowance for difference in elevation and water volume, will impress any person with a sense of prudence in undertaking to drop 15,000 cubic feet of water per second 60 or more feet into a pool immediately adjacent to the Panama Canal. There would be a commotion, to say the least.

The Mountain Tunnel Spillway Idea.

It would seem that the late Chief Engineer had a vivid conception of the advisability of avoiding this drop. We find that he had surveys made for tunnels through mountain ridges, to the length of 3.4 miles in one case and a much greater length in another case, whereby to divert the upper Chagres floods wholly away from the canal. If we

could be at all sure of the feasibility and the cost of this tunnel project we might cease consideration of the drop. But who can tell with positiveness what such a tunnel would cost, in such a climate, and in a formation not theretofore explored by tunnel? In the absence of some refrigerating plant to cool the air sent to the headings in that tunneling work, the temperature would be unbearable there. The uncertainties of cost of this proposed tunnel spill-way would exceed the uncertainties attending the below-water excavation for the sea level canal.

But what can be said of the certainties as to efficiency and safety, of such a tunnel after it should be completed. The Engineering Committee say: "If such a tunnel were "built at the elevation named, with a diameter of 30 feet, "it could be depended upon to discharge 15,000 cubic feet "per second, with the elevation of water surface at 180 to "185 feet, the mean velocity of water through the tunnel "being about 20 feet per second," I do not review the calculations involved in this determination. The main point is as to the effect of the claimed result. If that tunnel be not lined and is through material which would withstand the wearing effect of any such velocity, its interior surface would be so rough, with points and ridges and hollows of rock, that the mean rate of 20 feet of motion per second would not be attained to. The bitterly disappointing experience at what is known as Big Bend on Feather River in this State, in attempting to put a large volume of water through a rock cut tunnel with a carefully calculated section, should be studied by any one who wants to mature a judgment as to what can be done on the Isthmus of

Panama in that way. If the material is of a kind such as could be excavated and trimmed through to a sufficiently smooth or even plane to admit of the capacity being safely calculated, it would, if not lined, wash out under the influence of such a water volume and mean water velocity. If lined otherwise than in a very expensive manner it would be subject to rapid wear under such stress as 15,000 cubic feet per second, at a twenty-foot velocity, would put upon it. In any event, the uncertainties of cost, of capacity and of maintenance of such a work, would be so great that if possible it should be avoided.

Consideration of this alternative flood disposal scheme, was evidently suggested by projecting the water-way at Obispo below the level of the Chagres River junction with it. The lower in elevation the canal at this point, the more difficulty will there be in dropping the flood volumes to its level, and conversely, the greater will be the excuse for considering a tunnel relief proposition.

The Least Objectionable Alternatives.

But, if for other reasons we should reject the sea-level proposal and contemplate raising the canal plane, say, to the elevation of a one-lock-lift, we would have to compare the tunnel escape-way proposition with one to drop the waters between Gamboa and Obispo from about 60 to 30 feet of elevation. This drop would not be nearly so unmanageable as the 60-foot fall first spoken of. It might be broken up, within the available half-a-mile, into a series of cascades. But, if retained as a fall and located near the canal, cross currents tending to inconvenience navigation, probably would be engendered. Locating it up the river

nearer to Gamboa would of course, necessitate excavating a channel to it. Whereas, if the canal plane was adjusted to a two-lock-lift, the upper Chagres would enter it without drop whatever. The regulated flood flow could be divided, and part be led towards the Pacific and part towards the Atlantic. This would minimize current influence in the navigable waterway and leave only part of the upper Chagres waters to be dropped over an artificially cut spillway towards the Pacific, while the other part would be taken care of towards the Atlantic by the Gigante Spillway.

One-Lock-Lift or Two-Lock-Lift.

Beyond this point in the argument, consideration of the Gamboa-Obispo drop involves comparison of a 30-foot one-lock-lift canal with a 60-foot two-lock-lift canal. What advantage has the former over the latter? Economy in cost of the whole work? No. If the water plane at Obispo were at 55 to 65 feet elevation, so that the 15,000 second-feet allowed to pass the Gamboa dam could be received directly into it, the canal would cost about $16,000,000 less than if it was at the 30-foot plane and there had to be the drop spoken of. Greater efficiency of the resulting work? Apparently not. A two-lock-lift canal would detain ships in lockage only an hour more than the one-lock-lift canal. And enlargement of the water section itself, accomplished with part of the money saved by keeping the summit level at about 60 rather than placing it at about 30 feet, would enable vessels, in the greater speed attainable, to save much of, if not all the time taken for the extra lockage.

But I have now brought this line of argument to a point where my tentative conclusions are not so surely founded.

Starting with the sea level proposition, we have come to a point where the differences in merits and demerits of plans, as based on bottom facts and broad leading arguments, are not so great, and here it will be well to pause, and see how nearly we arrive at the same point in coming back from consideration of the highest level proposition. In doing so, however, remember this fact, that, the process I have followed has rested mainly on considerations of prudence.

A REVIEW: FROM 90-FOOT LEVEL, DOWNWARDS

The highest lock-canal proposition worthy of note, was that for the Panama Canal Company's Technical Committee, for a 97.5 foot summit plane to be supplied with water by a feeder canal from the river just below Alhajuela. This was an extreme, forced by considerations of economy in money and time which we do not have to heed. The same engineers really favored a 66-foot summit level. (Part I, pp. 11-13). Then came the Isthmian Canal Commission proposal for a 90-foot summit level fixed by a dam at Bohio. (Part I, pp. 14-15). This naturally forms our second extreme starting point.

The Difference Between Lock-Canal Proposals.

In their report (p. 69, folio edition) the Commission say: "The plan recommended by the Commission is, in its "general outlines, the same as the second plan recom-"mended by the French Engineers, the one preferred by "them, except for the time required for construction."

This is difficult to accept. If the Commission's plan—a 90-foot Bohio Lake and no Upper Chagres storage—is not to be regarded as distinctly a different plan from the 66-foot Bohio Lake coupled with the Upper Chagres Alhajuela reservoir, of the French engineers, not to mention a number of other differences which I have adverted to in the former parts of my writing to you, then we may as well stop consideration of the matter altogether. These two plans are about as different as any two lock-canal propositions can be.

The Merit of Simplicity in a Plan.

But, after saying their plan is practically the same as that of the French engineers, they continue: "The princi-"pal difference is in the height given to the Bohio dam, "and the important consequences resulting therefrom." Here we naturally would expect to have our attention drawn to "important consequences." But what do we find? The report proceeds: "A marked feature of the Commission's plan is its simplicity." Now, "simplicity" in itself, may or may not be an advantage, and to advance it as such is on a par with mere assertion without solid argument in favor of the sea-level plan for American National construction on the Panama route.

That kind of argument is sentimental. Simplicity in such a matter may be attended with such a marked and material disadvantage as to wholly negative other substantial advantage inherent in the plan itself.

For instance, in this case, we may gather from what follows in the report that having the one 90-foot Bohio lake in lieu of the 66-foot Bohio with the Upper Chagres

Alhajuela reservoir, constitutes simplicity. But is it simplicity to complicate the lake which is to serve at once as the Middle Chagres reservoir and as a part of the navigable water-way, with that which must serve for storage of upper Chagres floods, thereby necessitating a fluctuation of about eight feet in the water-plane of your navigable way? It is the navigable way which should be preserved without complication as far as possible, whose arrangement should have the attribute of simplicity.

Is there not simplicity in avoidance of forcing antagonistic functions, upon the same feature of a great machine? If so, the catchment of the Upper Chagres flood waters in a reservoir separate from the navigable water-way constitutes simplicity. The Middle Chagres navigable lake could then be held at more nearly an even elevation, and this would relieve not only its use, but the planning of its parts from many complications. On this point, it should be seen, that broadly, the French proposal is the simplest. But when we come to look at the bearings or consequences of the two plans, the French seems to give rise to much less complication and uncertainty, and we must accord it the credit of simplicity if freedom from secondary complication and uncertainty, as to cost and freedom from special risks, is to be the gauge.

The Claimed Advantages of Only One Lake.

But the Commission's report proceeds to show the claimed advantages of its plan over that of the French Engineers, from which, it started out by saying it did not materially differ.

"The increase in the depth and area of Lake Bohio "renders it possible to receive the full flood discharge of

"the Chagres directly into it without hindering naviga-
"tion." Is that in itself an advantage? As matter of fact, would it not be an advantage, for the sake of the water-way, if all the flood waters could be kept out of it? The making of the 90-foot Bohio lake as sole storage and sole flood regulator is in itself a distinct disadvantage to the navigable way because of the fluctuation of surface consequent and for other reasons presently given.

The Availability of the Gigante Spillway.

But the Commission claim for it these collateral advantages: that it enables them, (1) "to take full advantage of favorable topographic features of the country in the subsequent discharge of the surplus waters"—this means the Gigante Spillway—and (2) "the Alhajuela dam becomes unnecessary for flood control and its construction may be deferred until additional storage capacity is required, as the result of a large increase in the traffic of the canal in the future."

Now, as to the Gigante Spillway: While it was not incorporated as part of the record plans, as I understand, of the French Engineers, the site for it was discovered and its value fully recognized by them some time after those plans were outlined, but before our Isthmian Canal Commission made its examination and plans. General Abbott, our American member of the French Company's Technical Committee, intimates in his book that the Gigante Spillway had been recognized as an alternative part of their plan with the 66-foot Bohio lake.

Certainly it does not require the raising of Bohio lake to the 82-90-foot prism in order to take advantage of the

Gigante Spillway site. The Commission's own description of the Spillway, tells us: "There is good rock foundation "*at or above tide level* for the entire length of this spillway. "It consists of a dam entirely of concrete with a crest at "elevation of 85 feet, terminating in an apron at elevation "65, with a solid foundation below that level." This seems to show that a spillway can be constructed there as well for the 66-foot Bohio lake as for the 90-foot one. The rock foundation is "at or above tide level" and below the 65-foot plane. As a matter of fact it is contemplated, by the report of the Commission, to use the unfinished Gigante Spillway, after the foundation is laid in, as a flood escape at a low level during construction of the main dam at Bohio. Hence, this spillway site cannot be claimed as an advantage singular to the Commission's 90-foot-lake plan, or one not equally open to be used, in, we will say, a 50 to 66 foot Bohio lake plan. And, so, this claimed advantage of the Commission's plan vanishes.

The Advantage in the Alhajuela Reservoir.

But we are given to know that an advantage is secured in doing away with the Alhajuela reservoir. Just *what* advantage is not said. I have already pointed out that it is not an advantage on the score of "simplicity." It certainly is not an advantage on the score of safety. That Aljahuela dam was to be of masonry, on a firm rock foundation, unquestioned as a safe feature in itself; and it was to perform the function of keeping a very large part of the flood waters of the Upper Chagres in a separate basin until they could be doled out as required to the 66-foot Bohio lake waterway, to replace evaporative loss and lock use,

and this was an arrangement good for safety, as for other ends mentioned.

Unsoundness of the 90-foot-Summit Plan.

But it is not as to these points wherein the 90-foot Bohio lake project appears to be most unsound as an engineering plan. Observe: the waters are expected to fluctuate eight feet. To secure the 35 feet navigable depth at all water stages the walled channel for six miles through the deep cut will have to be eight feet deeper or the walls will have to be eight feet higher than would be necessary if the water surface were kept at one elevation. Now, this condition is secured by building a dam of immense proportions on a bad foundation at great expense and extreme risk, (Part I, pp. 28-33. Part II, pp. 57-62); and that dam, also, must be eight feet higher than if the water were held steadily at the low-water plane of the lake. Besides this, the Gigante Spillway, a masonry or concrete structure of immense proportions, is also run high into air to hold up this fluctuating 82-90 foot water surface lake; and all for what? Because of alleged "simplicity" and some other implied advantages which do not exist, and because, quoting the Commission's finally claimed advantage for their plan, "A great reduction also results in the amount of "excavation required to cut through the continental divide. "There is a material reduction of cost." But what the reduction in material or in cost actually is we are not told.

Bearing of the Gigante Spillway Feature.

The Bohio Lake eight-foot surface fluctuation may be urged as necessary in connection with an open spillway. But by the Commission's figures the crest of the Gigante

Spillway is planned at 85 feet, while the lake low-water plane is fixed at 82 feet. Here appears to be a clear economic loss of three feet. It would seem that, to save the cost of the Alhajuela dam, which would supply water to keep the surface steadily at the level of the spillway lip, the summit cut was planned that three feet deeper and an equal depth was added to the retaining walls; or, looking at it another way, the Alhajuela dam saving is bought at the expense of raising the Bohio dam and locks three feet higher than would be necessary if the Alhajuela reservoir were provided. It, of course, would require figuring on exact data to show comparisons of cost illustrating the above; but, the one-lake plan seems to be so unsound on general principles, on this score, that it would have to show a very material saving in cost to justify its adoption. A lot of objections to the consequences of it would have to be overcome by the money consideration. Some of these are, the additional and unnecessary pressure on the Bohio dam foundation, already a vulnerable and dangerous point; the additional and unnecessary height to the big cut retaining walls, already features liable to disaster; the additional and unnecessary height to the Gigante Spillway, in any event a colossal structure over which a vast volume of water will have to be dropped; and the additional and unnecessary height of lock lift, already, in the case of the 90-foot-summit plan, considered excessive by many specially competent engineers. Then, too, the mere additional and unnecessary three feet of water fluctuation is in itself decidedly objectionable for several reasons, which should be apparent and which I do not stop to specify. The main

point is that, if by an Upper Chagres storage reservoir the amount of water were opportunely supplied (as it could be) which is represented by the prism between the 82 and 85-foot plane in the Bohio lake, which amount the Commission allows for seasonal loss and use, then the lips of the spillway might be fixed at 82 feet, and the surface of the water be held there throughout the dry season, with all the advantages I name for the arrangement.

Advantages of Alhajuela Reservoir.

Thus it seems that an Alhajuela reservoir in connection with the Isthmian Canal Commission's Bohio lake plan would effect a number of important betterments to it. It would lower and cheapen its dam and reduce pressure on the questionable foundation thereof; it would lower and cheapen its Gigante spillway and diminish stress due to the water overflow; it would lower and cheapen the locks and diminish lock lift now gravely questioned; it would lower and cheapen 12 miles of immense retaining walls in the great cut and correspondingly reduce danger of disaster overtaking them; it would reduce the fluctuations of the lake's surface and render its margins less unsanitary, and make it a better navigation-way. Moreover, it would distribute volumes and risks, which is always a desirable thing in this class of hydraulic engineering.

Modification of the Commission's Plan.

Broadly, the 90-foot-summit work, it would seem, might be made an 87-foot-summit work by coupling the Alhajuela reservoir with it, to very great advantage, and, as far as we know, without materially greater cost; for, observe, the great cut would not have to be made any deeper, and

the saving on Bohio dam, Bohio locks, Gigante spillway, and great cut retaining walls would go towards meeting the cost of the Alhajuela dam, etc. But even this arrangement could be bettered, by placing automatic operating shutters on the crest of the Gigante Spillway so as to waste water, when necessary, at the 79-foot plane but still hold the low water surface at 82 feet. Thus we might, economically speaking, gain another three feet, to advantage, all along the line, as above, and to the special advantage of making extreme lock lift at Bohio 42 feet for each lock, in place of 45 feet. (See note at end.)

But, if the above changes were made, the plan would be a different one, and would, in truth, be like that of the French engineers, except in having an 84-foot in place of a 66-foot-summit level.

Some Closing Comparisons.

And now my argument has brought us to a point where the remaining question is as between a 60 to 66-foot-summit plan like that of the French Engineers, and an 84-foot-summit plan similar to theirs. We came up to the first plane and came down to the second. Here again the relative merits of the plans are not readily determinable on broad grounds or basic argument alone. We must appeal to structural details and to consequent risks or uncertainties; and, finally, to relative costs in money or in time.

The 84-foot or the 66-foot Level.

It may be conceded at once that an 84-foot-summit canal on the lines above laid down, would cost about $150,000,000, or about $25,000,000 ~~more~~ less than a similar 66-foot-summit work. It would probably take from one to two

years longer to build the lower and more expensive, than the higher and cheaper work.

The objections to the higher level are found principally in the greater dangers, risks and uncertainties consequent upon the higher Bohio dam and locks (see former parts of my writing), and greater lock-lifts and greater height of Gigante overfall. Another disadvantage might be that, a Gamboa Upper Chagres reservoir cannot so readily or to so great relative advantage be made a part of it, as it could in the case of the 66-foot-summit plan.

If, as the Engineering Committee declared is the fact, a Gamboa reservoir dam is entirely feasible, there would be much advantage in having the upper Chagres storage and regulator work located at that site, rather than at Alhajuela. It would stop all upper Chagres flood waters from being precipitated into the canal; the Alhajuela regulator would hold up only a part of them.

Probably, taking into consideration the more convenient locality and the cheaper form of dam possible for the site, the larger Gamboa reservoir could be made at not materially greater cost than the Alhajuela reservoir. If that be the fact, the Bohio lake fluctuation could be still more reduced, with benefit all along the line hereinbefore traversed.

The preponderating influence of these considerations seems to lean decidedly towards the lower summit level work of the two we are now considering. And just here, of course, the results of exact and comparable estimates would serve not only to check up my reasoning, but would show just what sacrifice would have to be made in money and

time to avoid the risks and disadvantages of the higher level work and secure the advantages and safety of the lower.

SOME GENERAL CONCLUSIONS

The Most Practicable and Feasible Plan.

It would seem, my dear Senator, that on the basis of such a course of reasoning, "the most practicable and feasible plan" for this Government to adopt in constructing the Panama Canal will be one with a Bohio Lake summit level, at about the entirely safe limit of a two-lock lift, one with a not excessive or unnecessary stress upon a Bohio dam foundation, and, at the same time, one in which the Gamboa lake (accepting the Engineering Committee's judgment on this point) can to good advantage be adopted as the upper Chagres regulator. This plan would have a summit elevation somewhere between 60 and 70 feet above mean sea base. It would be, in its outline, practically the plan of the French Technical Committee, except in the substitution of Gamboa for Alhajuela lake, and the substitution of the Gigante Spillway for the two spillways which that Committee's plans provided for near the Bohio dam. This is as near as general reasoning on the published data enables one to come to a conclusion as to the main question. Some other points may be added.

Possiblities of Enlarging Canals.

A sea-level canal cannot be made deeper without lowering its bottom by excavation. To effect this the walled portion of it must necessarily be built in anticipation of the deepening—the wall foundations would have to be deep enough

in the beginning to allow of the subsequent excavation of the waterway and still have their footings far enough *below* the canal bottom.

A lock-level canal can be readily made deeper, without materially interfering with the traffic upon it, by simply raising its banks and walls and raising and increasing the lift of its locks, and correspondingly raising its water planes.

Advantages of the Larger Canal.

Restriction in width and depth of waterway may constitute more of a handicap on commerce, by limiting navigation speed, than would delays at locks. Hence, a canal at a greater elevation but with a larger waterway may admit of the quicker as well as the safer passage of vessels.

Advantages of Lake Waterway.

In all that I have written I have said nothing about the provision of places for vessels passing each other in the waterway; but it is manifest that provision of such passing stations would be more difficult and expensive in a sea-level than in a high-level canal, because of the higher banks and longer slopes to be excavated in widening the channel at the passing stations.

In this connection, open lake navigation has great advantage as waterway, and the Bohio lake will be of collateral value on this account. But the 90-foot Bohio lake would afford but little if any advantage over a 65 to 70-foot one, for navigation length above Bohio dam, whatever elevation its surface after surmounting about 60 to 65 feet, would remain nearly the same. The river-bed elevation at Obispo, the head of the lake, is 40 feet. With a 65-foot water-plane

the excavation would only have to be 10 feet to afford the desired 35-foot depth, and the width of the valley up to this point, seems to be ample to give room for what would be, practically, open lake navigation. The higher water-plane, of course, would mean no excavation at that point, and greater channel cross-section, but if by a small amount of excavation a more than sufficient cross section could be obtained at the lower lake level, the advantage of the higher, on this count, would not be material.

With the suggested terminal lakes, (Part I, pp. 35-37, and Part II, pp. 76-77), the total possible length of lake navigation would be about as follows:

Atlantic terminal lake		
Mindi to Bohio	9.5	miles.
Middle Chagres lake		
Bohio to Obispo	13.9	"
Pacific terminal lake		
Miraflores to La Boca	4.1	"
Total	27.5	miles.

The advantages possible from terminal lakes have been sufficiently indicated on the pages of the first part of my communication, above referenced. My suggestions regarding them have been made only by way of pointing out that such possible features have never been considered on their merits, and that they should not be passed over in silence or disposed of otherwise than upon definite consideration. In my opinion, there need be no delay in construction occasioned by such field examination as would be necessary to obtain data on which to make this determination.

Further than this, it is impossible for me to advise you, because there is no data at hand on which to go beyond the limit of general reasoning, and this limit I suppose I have quite nearly approached.

A FINAL SUMMARIZATION

Two points I feel quite sure of: (1) That the United States should not attempt to construct a sea-level canal on the Panama route, and (2) that 90 feet, or any elevation over about 70 feet, is an excessive height at which to attempt to place the summit level. Considerations of business as well as engineering prudence, or what I hope you will regard as sound engineering judgment, primarily prompt both these conclusions.

Other conclusions are less well grounded to me. Economy and conservatism, prompt to conclusion in favor of a two-lock-lift canal with the water-plane about 65 feet above mean sea-level, while the sense that a one-lock-lift canal with a 30-foot water plane, might be the simpler machine of the two and less liable to injury by an enemy, militates in favor of it.

As a broad proposition, in my judgment, the money represented by the difference in cost between the higher and the lower-plane canal for the same dimensions of waterway, would be better expended on making a larger waterway on the higher profile and in increasing the proportionate extent of lake navigation, within the limits I have indicated.

If the attention of the members of the Consulting Board

is sharply drawn to the business aspect of the subject put before them, as I expect it will be, their report should set at rest much I have in an indefinite way attempted to talk about. If what I have said serves to enable you to judge, to specially good advantage and with a minimum of labor, of the report when it comes, my prime purpose will have been served.

In my opinion the American people will want a canal soon or not at all. They now feel that they may want it in their national business, so to speak. A 7 to 10-year, $150,000,000 to $170,000,000 proposition might "go," though a 14 to 16-year, $200,000,000 to $230,000,000 one, might not. The cheaper and quicker constructed work would be a good one, and the fact that the more expensive and longer time one would be better, would not save the situation. It would be a monstrous disaster to fail in this enterprise. Who knows what commercial and political crises are to come within the next decade or very shortly thereafter?

Respectfully yours,

WM. HAM HALL,
M. Am. Soc. C. E.

NOTE

In closing this subject after the foregoing was in type I endeavor to make myself clearer as to the obtainable effect of upper Chagres storage in preventing fluctuation of a Bohio navigable-way lake.

The Isthmian Canal Commission's plan, with the lip or crest of Gigante Spillway fixed at 85 feet of elevation, contemplates a low water drop in the lake to 82 feet, and all other structures are planned to admit of this, as explained on pages 29 to 32, foregoing. The three-foot drop of water surface below the spillway lip, from the 85 to the 82-foot plane, would be occasioned by excess of loss and use of water over and above current supply during the dry months. The five-foot rise of water surface above the spillway lip, from the 85 to the 90-foot plane, would be caused by the inflow of floods at some period or periods within the rainy season, and during this time water would be wasting over the spillway. An upper Chagres reservoir would catch and hold most of the flood waters which would come to it within short spaces of time after heavy rains, and allow them to flow, in comparatively small and manageable volume, to the Bohio Lake during the longer spaces of time between rains, and would hold a full volume in store at the end of the rainy season.

According to the Engineering Committee, the Gamboa reservoir they projected would hold all the upper Chagres flood volumes after allowing about 15,000 cubic feet per second to flow continuously. This 15,000 second-feet would be currently received into the upper end of Bohio

Lake and as promptly wasted over the spillway towards the Pacific, or over Gigante Spillway towards the Atlantic, and, hence, the Gamboa reservoir would serve to prevent upper Chagres floodwaters from raising Bohio Lake water surface much above the spillway lips. As, according to the Commission's report and General Abbott's book, the upper Chagres delivers more than half the water which reaches Bohio, the retention of upper Chagres flood waters would, proportionately (but for one consideration presently to be noted), diminish the rise of Bohio Lake surface consequent upon floods. That is to say, instead of being 5 feet the rise would be less than 2.5 feet. With a fixed-lip spillway this would not work proportionately, though, for the waters would not waste at all until they had risen some above the lips, and the volume of flow over a spillway increases in greater ratio than its depth. Nevertheless, the impounding of upper Chagres floods in a Gamboa reservoir probably would reduce Bohio Lake fluctuations by about one-half, as above.

Finally, the waters thus impounded would serve to supply loss and use from Lake Bohio and keep its surface plane at elevation of spillway lip throughout the dry months.

Thus the 8-foot fluctuation contemplated by the Commission would by the Gamboa reservoir be reduced to about 2.5 feet, with the benefits I have called attention to. This may be modified by the length of spillway not being sufficient to take at 2.5 feet of depth all the waters brought to it. But probably this could be adjusted. Sluices through the spillway (or a movable crest by any of several designs) could be made to keep this surface fluctuation within even a smaller limit.

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